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NATIONAL SECURITY STUDY GROUP

The National Security Study Group (a.k.a., "Hart-Rudman Commission") is pleased to post the following paper, entitled "Technology, Society, and National Security," on the NSSG web site. This paper was prepared by NSSG staff on the basis of an extended research, workship, and interview effort. It was designed to serve two purposes: to inform and stimulate the thinking of the NSSG Senior Advisory Board in advance of its April 5-6, 1999 seminar; and to provide a building block in the process of completing the NSSG Phase I report, which is mandated by the NSSG Charter to be delivered no later than August 15 of this year. While this paper is in fact serving as a building block for the Phase I report, it will not be replicated verbatim in that report. It would therefore be inaccurate and misleading to think of this paper as constituting formally a part of the NSSG Phase I report.

"Technology, Society, and National Security" is one of five papers produced by the NSSG staff for its April 5-6 Senior Advisory Board seminar. Other papers will be posted in this space in due course. Visit the NSSG web site often, and keep abreast of our activities. As always, we welcome your comments, constructive criticism, and suggestions for further research.

We look forward to reading your comments in our
Future Tech Forum

NEW FUTURE TECH FORUM

March 29, 1999 *Pre-Decision Draft*

Technology, Society, and National Security

The Charter of the National Security Study Group calls for a Phase I Report by August 15, 1999 that describes the national security environment that will likely exist in the first quarter of the 21st century. The charter enjoins the NSSG to assess threats and opportunities that the United States can reasonably expect in political, economic, military, societal, and technological terms. This paper focuses on the potential macro effects of technology based on current trends and expert opinion.

Technology represents a major force affecting all the productive processes in society. As such, technological innovation is a major if sometimes indirect driver of political change, social relations generally, and military-security arrangements in particular. Technology and social reality, however, are joined in a dialectical relationship. Not only does technological change affect social relations¯indeed, even how the human cognitive apparatus reacts with its surroundings¯but human culture affects the uses and generation of technology. Taken together, the interaction of human cultures and technology is an obviously important facet of any overall strategic environment, particularly when notable shifts in basic orientation take place.

Arguably, such a shift is in progress today. Until the 1970s, the reigning industrial-technological paradigm smiled on size. Factories grew larger to serve global markets, buildings grew taller, continents were linked with rails and concrete, and vehicles moved faster. Gigantic rockets lifted men to the moon and, with 50-megaton warheads, underwrote the nuclear standoff. Then, energy shortages, environmental exhaustion, integrated circuits, and gene splicing heralded a new direction. Seekers after scientific-technical revolutions must now look toward smaller but interactive, intelligent, and distributed systems that lead to more "transparency." The leading edge of scientific breakthroughp, and hence of technological innovation, is shifting as well, in two related directions: (1) toward the creative merging of many cutting-edge technologies; and (2) toward the more inclusive integration of the natural and social sciences under the influence of complex systems theory.

This paper does not pose specific technology paths or "pick winners" for the future, but rather provides an overview of a range of technologies that will impact global society within the next quarter century. It seeks, too, to examine an array of potential social and policy outcomes based on technological innovation. It thus poses two sorts of questions. First, it asks 'What if?' questions that concentrate on potential *applications* of future technologies: If a certain technological feat were possible, what might we do with it? Second, it asks 'So what?' questions that consider the social *implications* of technology: If a certain technology comes into widespread use, how would it change the nature of work and leisure, or military logistics, or relative power relations among groups or states?

In addition, the paper takes up briefly the impact of technology on the natural environment and the world energy balance, possible technological and environmental "wild cards," and the national security implications of the technological innovations sketched out herein.

This paper will ultimately be blended with other functional analyses and a series of regional analyses into the requisite product for Phase I of the National Security Study Group: an assessment of the overall national security environment for the United States between now and the year 2025.

A Baseline Technology Prospectus through 2025

Technology consists not only of things, or devices, but also the way that devices are combined and put to use. Hence, the following discussion is divided into a discussion of devices and of likely means of technological adaptation and integration.

Devices

MICROELECTRONICS, COMPUTER NETWORKS, AND COMMUNICATIONS

• Cheap, high-density microelectronics will proliferate in all our tools and our physical environment. The number of transistors per chip will continue to double every 18 months until roughly 2005 or 2010, when we will run up against the physical limitations imposed by reaching the atomic scale. This physical limitation, however, need not signal the end of progress, for while today's chips carry an essentially two-dimensional architecture, future ones may be three-dimensional.

• As processing power continues to expand, *it also decreases in cost*. Today $1000 buys about a billion computations per second. By the year 2025, $1000 of computing will buy about ten billion billion computations per second. Like processing power, memory capacity will continue to double roughly biennially, and prices will drop accordingly. In 1970 one megabyte of memory cost half a million dollars; in 1996 it cost $38; today it costs less than $3. Our ability to pack information into ever-smaller volume, and ever more inexpensively, will continue to increase. Nobel Prize winner Richard Feynman dramatized the phenomenon by noting that, *theoretically,* one could put the *Encyclopedia Britannica* on the tip of a pin. More important, such capacities will provide a basis for major changes in how business, education, and government handle information.

• Between now and 2025, fiber optic capacity will surpass terabaud rates, which is to say, a thousand billion bits per second. As with electronics, greater power is matched by declining unit costs; cost per network node appears to drop by a factor of 10 every five years. Fiber optics will thus serve as the backbone of an integrated global communications network. Whereas optical fiber communications has until now been limited by the deterioration in the signal power over long distances, new fiber amplifiers will allow signal transmission over thousands of miles of optical fibers. Moreover, the number of signals traveling through a single fiber will increase greatly due to the ability to transmit multiple wavelengths (or colors). Fiber communications will probably be viable for residential use by 2010, as well.

• Between now and 2025, wireless communication systems (space-based and land-based) will be highly integrated with the fiber-optic backbone to provide specialized and niche services. Constellations of communications satellites will enable voice, E-mail, paging, and limited

Internet service from any point on the globe to virtually any other point on the globe. Direct broadcast radio and television is already lifting the electronic silence of the developing world. Cellular and wireless local loops are augmenting telephone capacities worldwide. The implications of such capacities for the abilities of authoritarian regimes to cordon off their populations from information and news are enormous. Compared to the effects of the transistor radio in Africa and Asia in the 1950s and 1960s, and of the audio cassette in Iran in the 1970s, the impact of a fast-"wired" world on the clinging autocracies of the next century may be even more dramatic.

Micro-electromechanical Devices, Micro-fabrication and Nano- or Molecular Fabrication

• Between now and 2025, MEMs (micro-electromechanical devices) will become a major commercial industry. MEMs are microscopic devices in which sensors, transmitters, receivers, or actuators (switches that activate mechanical devices) have been miniaturized to the size of a transistor. The tools that make today's computer chips also make MEMs. MEMs are already being used to detect movement to activate air bags, but they can be constructed to detect a variety of visual, thermal, acoustic, and biochemical phenomena. Imagine trying to find a bugging device where you need a microscope to see it. MEMs have demonstrated usable micro-watt transmissions, and miniature motors have power production capability with an energy density ten times higher than the best batteries. New "smart" materials will be constructed with MEMs that have micro-scale features; for example, airplane wings with micro-structures will change shape automatically to allow better control and flight efficiency.

• Other micro-fabrication techniques will allow the construction of matrix composites of great strength, low weight, high heat tolerance, and low cost. Ceramic composites will enter car and jet engines. Other microstructures have been exploited to develop "see-through" metals, substances that are hard and not brittle, but still transparent.

• Nano- or molecular fabrication—the taking of micro-technology down to the atomic scale or dimension—is now in its early stages. Applications will involve the manufacture of nano-scale structures that can be embedded on other electronic devices or on materials. Texas Instruments has already manufactured an array containing a half-a-million movable nano-mirrors for a tiny high-resolution projector. In 1997 nano-technology was an estimated five billion-dollar industry, and it is optimistically projected to double each year over the near term. Nano-fabrication will be available commercially only to a limited extent by 2025, however.

Biotechnology

• Bio-technologies may eclipse information technologies after the year 2010 in terms of economic investment and economic impact. Both the commercial world and governments have sustained large R&D funding. This funding and the remarkable developments in genetic engineering, tissue-growth research, and the human genome project will spur rapid growth and innovation. Some of the key developments and indicators are:

—The mapping of the human genome offers the prospect of making significant strides on the link between genes and disease. Scientists are learning how life works and fails to an ever finer level of detail, and they are learning with it the pathogenic and genetic correlates of disease. Gene therapies, even in the fetus, are likely. Cells that can normally replicate 50 times will be adapted to be able to replicate 200 times or more. This has started a debate on the possible discovery, and social implications, of a scientific-technical "fountain of youth."

—The mapping of animal and plant genetic makeup offers the capability to tailor animals to serve human needs. Agriculture will be transformed with the promise of higher productivity, nutrition- and vaccine-enhanced foods, and greater plant resistance to (known) pests. "Farmaceuticals" will be readily available. Cows, pigs, and sheep with altered genes will provide proteins with medical value in their meat and milk. Bacteria are already being used for environmental remediation; for example, to clean up oil spills.

— Cloning human organs will be possible by 2025. Animal and human stem cells are now being grown in the laboratory. With the appropriate signals, stem cells can be converted to any specific cell. It is possible to extract one's own tissue and transfer the DNA to stem cells to generate transplant tissue that your body will not reject. Mouse heart cells have been created from stem cells. Overall, these developments will probably extend the average human life span to at least 85 years in the developed world within the next 25 years. At least theoretically, those born after 2020 may look forward to a life span considerably longer than that.

Technology Integration in the Next Quarter-Century

Our use of technology has been revolutionized by the way we integrate and conceptualize its use and distribution throughout society. The following discussion highlights what we may expect from science and technology integration over the next 25 years.

COMMUNICATIONS, SENSORS, AND TRANSPARENCY

• The Internet, new sensor capabilities, and global communications greatly facilitates both commercial and military intelligence gathering. Mature communications and sensor systems are allowing images, voices, and data from around the world to be gathered and shared. Small personal communications devices will allow point-to-point communications within a 50 to 100 mile radius; in short, the fabled Dick Tracy wristwatch of comic book imagination is now reality. Such a watch could include a GPS receiver to keep track of position. Portable communications devices will provide Internet entry throughout the world, allowing near-instantaneous and independent exchange of commercial and technical information, exhortations and complaints, political ideas and manifestos.

• Small cheap microphones, electro-optical compact disks, biochemical detectors, and pocket radars for military, security, biomedical, or controller applications will advance sharply. At least one, and perhaps several commercial surveillance satellites will be able to image at or slightly below one meter resolutions at optical wavelengths. Commercial all-weather imaging based on synthetic aperture radar (SAR) at two-meter resolution may follow. Many satellite owners may be free of U.S. "shutter control," which is to say that both collection and dissemination of such

• *The merging of information technologies and positioning technologies*. Witness the explosion in commercial applications since the introduction of the Global Positioning System (GPS). With that technology cargo and its transport can be tracked, leading to better logistical control. Harbors and airports control traffic using GPS. Farmers plow and plant crops using precision GPS. By 2025, monitoring and analysis of much of human and environmental activity will contribute toward the transparency described above.

• *The merging of human-interface technologies with other tools and with our environment.* Speaker-independent voice recognition will be available. You will be able to talk to and instruct a wide range of appliances, your computer, and controls that manage your work and home environments. Machines will have sensor devices that will change behavior according to perceived human bio-function readings; for example, your car may not let you drive it if you are too intoxicated.

• *The merging of miniaturized power source technology with micro-electromechanical devices.* MEMs devices will have embedded power sources allowing sustained stand-alone performance. Consider, for example, a MEMs transmitter-receiver and bio-sensor that operates in a remote area for a week or more, which today would require much larger devices requiring more energy.

• *The merging of bio-technology with micro-electronics.* MEMs sensor devices have been fused onto insects. Soon the direct interface of micro-electronics and animal or even human tissue will be possible. Sensing and detection of the environment (bio-toxins, pollution, and so forth) will be linked to the automatic transmission of data. It will no longer be a matter of science fiction on the one hand, or philosophical abstraction on the other, to say that humans and machines co-evolve.

Complexity Theory and Interactive Technological Systems

Complex systems theory will significantly alter how we view and interact with the world. We will arm our computers and information technologies to use complexity theory to conceptualize the world in a more global, ecological, and dynamic perspective. Today we look more toward nature and naturally occurring complex systems to garner ideas about how to solve a variety of problems; e.g., ecological problems and network security problems. We now use the term "biomimicry" for the process by which ideas are obtained by imitating nature. Complexity theory is too new to know what its full implications may be, but it is already having a major impact on inter-disciplinary studies. Some indicators are as follows:

—*Adaptive agents are being developed*. Adaptive agents are entities that exist in a computer that imitate human agents in some limited form. Computational genetic algorithms will be used extensively to explore or to solve a large variety of problems¯from controlling electric and gas distribution systems to analyzing the effect of natural disasters on an economy. Computer programs that use genetic algorithms to create software that can solve problems better and faster than traditional programs have already been developed. In future we may use software based on genetic algorithms to fly airplanes. New computer architectures will be developed based on human brain functions. Computer architectures that take advantage of the sort of parallelism characteristic of neurological functions in the brain have already been developed, and research is likely to lead to more human-like capabilities.

—*Adaptive agents, or "knowbots," will garner any unprotected information we need on any network.* The universal access to information, particularly tailored information, will create the need to maintain a robust monitoring of world developments. Complex adaptive systems (CAS) theory, a subset of complexity theory, is being used to model social interactive systems. We are already developing land warfare models that simulate the interaction of enemies with specific characteristics. By 2015 we might have the prototype of a reconfigurable networked multi-sensor weapon system that adapts to enemy tactics automatically based on use of adaptive agents.

Technology and the Global Environment

Humans have survived broad and rapid changes in the environment over history. Technology and mediating institutions have improved our ability to adapt. For example, technology can both reduce and clean up pollution, insurance allows people to overcome occasional natural disasters, and public health and sanitation helps protect mankind from epidemics. The next twenty-five years may pose no catastrophic environmental problems, but the closer mankind operates to nature's edge, the more chances it takes. The *lack* of technology as well as the *application* of technology causes many environmental problems; and our use or abuse of technology could help us improve or exacerbate the situation.

Five environmental concerns of special note are as follows: deforestation, global warming, aquifer depletion, lost bio-diversity, and emergent diseases.

Deforestation is a phenomenon of the developing world. (Forest coverage in North America and Europe has risen steadily since mid-century). Huge forest fires, caused by a combination of human actions and climatic conditions, devastated southern Mexico and Indonesia in 1998¯something that is not supposed to happen to tropical forests. The direct consequences of deforestation include erosion (which ruins farmland), faster rainfall discharges (which contributes to flooding), loss of habitat, human exposure to new diseases, a shortage of fuel (firewood) whose gathering then consumes ever more time, and a reduced global ability to absorb anthropogenic carbon dioxide.

As to *global warming*, global temperatures in 1997 set a record unseen since the 1400s. In 1998, helped by a strong El Niño effect, global temperatures set a record increase of 0.2 degrees celsius. The possibility that global temperatures have been kicked into a stronger warming trend cannot be completely discounted, although the scientific evidence is far from conclusive. There is enormous controversy and considerable uncertainty in interpreting what the data in hand means. If the negative predictions are correct, however, global warming could have three potential effects: extreme weather, rising sea levels, and ecosystem disruption.

—With more energy in the atmosphere, extreme weather may grow more common. Recent floods in China displaced more people than now live in France. In other places, droughts may worsen. The evidence linking atmospheric warming to extreme weather is, however, not conclusive.

—Although the effects of global warming are concentrated in the polar latitudes, this is precisely where glaciers are found; their melting, plus the thermal expansion of ocean water, could raise sea levels. This, if combined with more frequent storms, could lead to greater coastal flooding.

—Third, ecosystems may not adjust smoothly to "rapid" climatic changes. Deadly pests and pathogens could migrate outside their normal habitats denying large swaths of land to agriculture for extended periods.

Aquifer depletion is already harming the agricultural productivity of India, China, and several Middle Eastern countries, with water tables in some cases falling a full five feet a year. Agricultural productivity in some places may fall by as much as a quarter by 2025. Such consequences are not inevitable; the Ogallala aquifer in the U.S. southern plains has been stabilized through deliberate public policy. Efforts are afoot as well to monitor and regulate aquifer usage in the Jordan Valley and elsewhere in the Middle East. The fall in productivity caused by aquifer depletion could also be partially offset by increased yields from genetic engineering, hydroponics, cloud-seeding, and advances in desalination technology.

Reductions in biodiversity are mourned because of the actual consequences on species and for the lost opportunities (e.g., for new pharmaceuticals). Monoculture¯plants not only of the same species but with the same genes¯is advancing. A pest lucky enough to be a tight match to the reigning genotype could propagate unchecked. Monoculture also gives adversaries a better opportunity to devastate the agriculture of their foes by propagating plant diseases or super-pests.

Emergent diseases could become a major problem of global proportion. In the last twenty-five years more than twenty new diseases have been identified, ranging from toxic shock syndrome and Legionnaires' disease to the Hanta, Ebola, and Marburg viruses. Malaria is making a comeback, and multiple-drug resistant tuberculosis is primed to infect several hundred thousand in Russia by 2025. AIDS may doom one of every three Africans born south of the equator since 1980 to an early death, and India's infection rates now number in the millions. Very large cities with poor sanitation have always been prime incubators for disease, and urban populations in the developing world are expected to double or triple by 2025. Current and future transportation systems also provide unprecedented opportunities to spread deadly communicable diseases.

Technology and Energy

In terms of global energy demands, technology will not provide a miracle cure for the world's current dependence on fossil fuels by 2025. Coal and gas liquefaction are not so much technology issues as economic and infrastructure issues. Technology will improve solar power, wind power, and other energy "scavenging" methods, but not to the point of significantly meeting all new energy demands.

Renewable energy sources (for example, crops grown to produce ethanol) could be genetically engineered to produce higher energy volumes. Ultimately, however, they must compete with future fossil fuel prices and alternate demands for food crops and land use. Technology will improve engine efficiency within motor vehicles, and hybrid fuel cell engines will emerge that are both gas and electric powered. Also, the ability to do more with smaller devices, as sketched briefly above, will to some extent reduce fuel needs. But this will only mitigate, not eliminate, the current dependency on fossil fuel.

Technological and Environmental Wild Cards

The world of technology is enormous and the full range of possibilities that may emerge from that world is impossible to imagine. However, some possibilities need to be considered just because the social and political implications are very great. Three examples are quantum computers, the finding of a major new energy source, and the full development of "self-assembling" nano-technology.

Theoretically, quantum computing is possible, but it is unlikely within a 25-year time frame. If it were possible, however, we would have to radically change how we protect information using encryption, for quantum encryption will inevitably follow quantum computing. Indeed, quantum computers would have the capability to break the typical codes in use today and any codes projected to be developed over the next two decades.

The introduction of a major new source of energy would be of huge economic, political, and military-security significance. Some scientists believe that such a new source lies with the prospect of cold-fusion, or of tapping into the "zero-point energy" that lies everywhere in the universe. "Zero-point energy" refers to random quantum fluctuations of the electromagnetic (and other) force fields that are present everywhere in a vacuum. Most scientists question the possibility of ever being able to commercially exploit such energy. Research efforts on fusion, "hot" or "cold," have not yielded the desired capabilities either. However, if a major new energy source is found, energy shortage problems could be solved and many international political relationships dramatically altered. At the same time, the global economy would be radically perturbed.

The greatest potential of nano-technology lies in the development of self-assembling nano-technology devices. This capability is unlikely to exist within the next 25 years. Hence, nano- or molecular fabrication is unlikely to mature to its full commercial potential by 2025. Nevertheless, nano-technology will be an arena of intense research and development effort, and of limited but possibly very consequential applications in the military arena. Nano-technology is the next step down in scale of micro-technology. Nano-technology is literally the construction of devices "one atom at a time." We are talking about devices sized at the molecular level akin to those manufactured by our own body that can manufacture themselves in large quantities. Imagine a microscopic motor produced by molecular assembly techniques. If nano-technology can be accelerated, the payoff will be tremendous.

As far as environmental wild cards are concerned, it would be wise to consider two potential wild cards related to global warming. The disappearance of the warm-water conveyer belt in the North Atlantic—one theoretical consequence of warming trends according to some tentative computer models—would give northern Europe weather patterns similar to those of northern Ontario. The breakup and meltdown of the West Antarctic ice pack would flood some of the world's biggest cities. While such events would happen fairly gradually, and thus give some warning, they would be very hard to reverse within reasonable time frames.

Implications for National Security

Technology manifests itself in society less through its absolute capabilities than through its interaction with the complex human systems. So complex is this relationship that we do not even know the specific course on which our own technological innovations have launched us. However, we can point out the issues and debate the environment that we will likely face within the next 25 years.

Anonymous intimacy will deepen because of globalized information.

- Technology will allow the typical Internet user to connect to the Web by "mouth and ear" in addition to "touch and sight." Any question in any major language may be met by an answer. Through artificial intelligence and adaptive agents the context of any question (and thus how to frame the answer) will be known automatically. This capability allows anyone anywhere to gain access to knowledge that can be used to the benefit or detriment of anyone, any group, any country, or to humanity as a whole. Global inter-connectedness will give more people access to more information than ever before, aided by "knowbots" and high-accuracy universal translators; faster processors will give them new ways to work with it, as well. Among other things, this suggests a growing gap between those few individuals who can afford and use the technology, and the mass of the world's population with limited access to it.

• The real world is becoming more intimate via the virtual world. Individuals will be linked to cyberspace through eyeglass attachments. Further linkages directly into their eyes, with contact lenses for example, are theoretically possible. By such means, direct sensor information (e.g., infrared, ultraviolet, light polarization) may be fused directly onto the visual sense, of which aviation heads-up displays are but a simple precursor. At the same time, machines will become more sensitive to peoples' faces, the timbre of their speech, and their gestures. Some people will not like the results, but others may see in them a means of limiting still further interactions with other human beings, thus reifying class structures as well as educational and linguistic boundaries among social groups. For those who like human contact, the ability of computers to render others beyond arms reach increasingly more vivid (e.g., as with very high quality videophones with pheromones) may heighten the impact of virtual communities formed by those of similar social or ethnic background (e.g., the Kurdish or Armenian diasporas) or of similar interests (from animal rights activists to coin collectors). Obviously, some virtual communities will have more political content and salience than others.

• The uses to which we put information are difficult to foresee. On the one hand, the most commercially successful enterprise on the World Wide Web right now is pornography. On the other hand, there are indications that people are using the Internet to process information and solve problems in new ways. The global information network suggests many implications for improved intelligence, C4ISR, knowledge management, training, and education of both the populace and the military.

Trustworthiness cannot be assumed in cyberspace.

• Technology could facilitate the spread of false images and information, while culture and governance will probably try to restrict access to personal data. There will continue to be competition between transparency and privacy, with technology serving both sides. Global interconnectedness, sensor technology, and improved information technology will increase the amount of information available on each of us, inevitably facilitating the misuse of it by some. Information networks will continue to be targets. So far, the attackers of such networks have yet to cripple a major system, but the battle is intensifying and the ability to "hack" into networks has been "democratized." In 1999, over 10,000 web sites offered information to novice hackers. Many of these had downloadable programs that automatically probed for weaknesses in networks and common operating systems such as Windows NT, Windows 95/98, IBMs OS2, and UNIX. The ability to write computer code is no longer a prerequisite to perform mischief. The complexity of the systems involved makes accurate prediction impossible. The most exploitable element in networks and "firewalls" remain the procedures associated with user access codes. Biomimetics will improve the security of user access codes in the future through user specific biological data.

• Total information security is not possible and global use of encryption will be limited by standardization protocols and government regulations. While encrypted communications may become the norm, it is unlikely because the impact of high encryption on overhead cost in money and efficiency, and the ability of high-end computers to crack low-end encryption makes regularized encryption cost more than it is worth. Theoretically, the advantage lies with encryption; practically speaking, it may not.

In a transparent world, attempts to dominate neighbors through heavy metal face long odds.

• The winning edge of a modern conventional military may have shifted from the ability to mobilize forces, through the ability to mobilize fires, and on to the ability to mobilize information. The U.S. military is on a course to being able to detect and defeat armored invasions within days using stand-off fires. Better stand-off weapons are in the cards. Even “short-range” missiles will improve range, accuracy, and guidance, which will increase the probability of target kill.

• Increased reliance on space systems is likely to create both new vulnerabilities and opportunities. Space offers an arena of international cooperation, but it also risks proliferation of technology. Placing weapons in space will be increasingly likely. If a gram can be put into orbit for one dollar rather than ten, then space-to-ground munition rounds may become cost-effective. Oft-touted ground-targeting lasers, high-power microwaves, and neutral particle beams are also possible. They offer near-zero time between spotting and hitting a fleeting target, but they must be fielded in constellations to be in position when fleeting targets show up, and atmospherics impede their use. Space weapons can also be provocative; it does not take much imagination to get the sense of foreboding that would come with looking up and constantly seeing enemy spacecraft that could kill you with absolutely no warning.

• Even without space weapons, supporting investments (e.g., sensor-to-weapon linkages) should take the U.S. ability to halt “heavy metal” incursions from the calculus of warfighting toward the realm of conventional deterrence. Like nuclear war, conventional war as we have known it may be planned in total seriousness, but without real expectation of being used. Unfortunately, the same logic puts the large ceramic, steel, or titanium boxes that U.S. forces now field in similar peril. PGMs are proliferating. Commerce supplies most of the information technology behind observing, orienting, deciding, and coordinating actions, which are therefore available to anyone, and for less money with every passing year. Stealth helps but it is expensive and therefore likely to be used for only a few platforms. Moreover, because anything that moves must disturb its environment, current stealth technology must ultimately fail before continual and exponential increases in the ability to collect and correlate data.

Future technologies may not prevent natural disasters.

• The impact of environmental degradation on international security depends on how people react to that degradation. The prospect of water shortages in India or China¯both expected to be armed with nuclear-tipped ICBMs¯may impel each to seize water-rich areas to their north. Just as likely, however, it may induce them to institute long-range planning to lower water usage and ease peasants from agriculture to urban occupations. Or, it may provide the impetus for lacing Asia with water pipelines, thereby increasing mutual interdependence and inhibiting conflict.

• Even with mediating technology, resource depletion and environmental degradation may increase the frequency and intensity of conflict. Purely natural disasters (e.g., Hurricane Mitch) could, in and of themselves, touch off a large exodus from affected areas that, in turn, destabilizes the broader region. A city used to absorbing 100,000 migrants a year may cope; one that sees little movement in a decade and then suddenly a million migrants after a drought may not. State failure brought on or exacerbated by disaster may complicate U.S. efforts to combat organized crime or terrorism. For instance, disasters that force victims up against or across borders may increase international tension. Further pressure to migrate to the United States (or to its allies) would be a national security issue on its own.

• Environmental consciousness is already affecting the U.S. military, which is not only responsible for remediating the effects of its own facilities, but also using environmental-friendly ammunition (e.g., replacing depleted uranium rounds). Meanwhile, potential opponents have shown a willingness to use environmental pollution as an offensive weapon—as when Saddam Hussein used oil fires to pollute the land and sea environment in Kuwait in February 1991.

To find the next apocalypse, think bugs not bombs

• Bio-technology holds great promise but also great risk. While there is no classic military use for biological weapons, they could be used by terrorists. A biological pathogen could also be released inadvertently. Biotechnology and the specter of cheap weapons of mass destruction bring an increasing imperative to a search for new means of prevention or, lacking that, an appropriate defense. In the event of failure to prevent their use, a robust consequence management system is necessary.

• Weapons of mass destruction will become more easily available. Current biological weapons pose a special limited threat because they can be produced cheaply and without the level of expertise required for nuclear devices. They are also more difficult to keep outside our borders. The good news is that biotechnology may offer some antidotes and shields, and MEMs technology is being directed toward defensive measures. One danger of which we must be aware is that the successful use of a WMD against a population center will likely create effects, such as panic and shock, disproportionate to the casualties it causes. Such an event could trigger changes beyond our ability to control. Consequence management needs to be carefully considered.

• More apocalyptic is the problem of a genetically engineered product ¯ weaponized or not. Highly virulent, infectious and "contagious" germs with long-latency and multiple drug-resistant characteristics could be developed. More sophisticated genetic weapons could also be constructed that selectively targeted plants or animals, including humans, with specific genetic traits. Whether such "bugs" were released on purpose or by accident may, in the end, be irrelevant.

Macro-policy Implications

Technological change has brought us to a crossroads. Indeed, not two but three roads are meeting:

- First, the proliferation of micro-technologies, computer networks, and distributed processing power, though offering tremendous new commercial and military capabilities, bring with them new categories of threats. These technologies cut horizontally across all functional areas and challenge the traditional boundaries of national security. It could be a major problem to cope with the issues of information assurance, information protection, and the prevention of disruptions to critical infrastructure functions that rely on information. Much of the problem lies with “motivating” people and institutions to *adopt* appropriate protective measures as it does with the development of the measures themselves.

- Second, in the future MEMs devices will able to perform many functions now done with macro-technologies. The combination of sensors, electromechanical devices, communications, and efficient energy sources into devices or onto chips brings a tremendous capability to collect and manipulate data. It will also provide the ability to perform many activities that currently require much larger macro-technologies. *We will not be the only ones using this technology.* Potential enemies will also be using MEMs, because many other countries are investing in this area. Given the small size of these devices, proliferation will be well nigh impossible to control.

- Third, we now have the potential to alter or change “nature’s program,” and the implications are enormous. Many of the technologies that appear feasible¯man-machine interfaces and bio-technology, especially¯bring us face to face with elemental questions. Who will we be when we can control our genetic makeup and incorporate machines within our bodies? How will our society adjust to the idea of clones? We are closer to having to face these questions than many believe. We may be on our way from being Homo Sapiens to becoming Homo Geneticus. Bio-ethics will become a part of the debate over national security as never before.

Between the proliferation and “democratization” of information access, the miniaturization and merging of critical devices, and the amalgamation of bio-technology across many realms of human endeavor, we can look forward to a transformation of our man-made context over the next 25 years perhaps no less dramatic than the transformation afforded over the last century by such now commonplace technologies as electricity, antibiotics, telephony, the internal combustion engine, air flight, contraception, and personal computers. Just as these technologies changed human societies in ways no one predicted, so the next 25 years of technological innovation is very likely to do the same.